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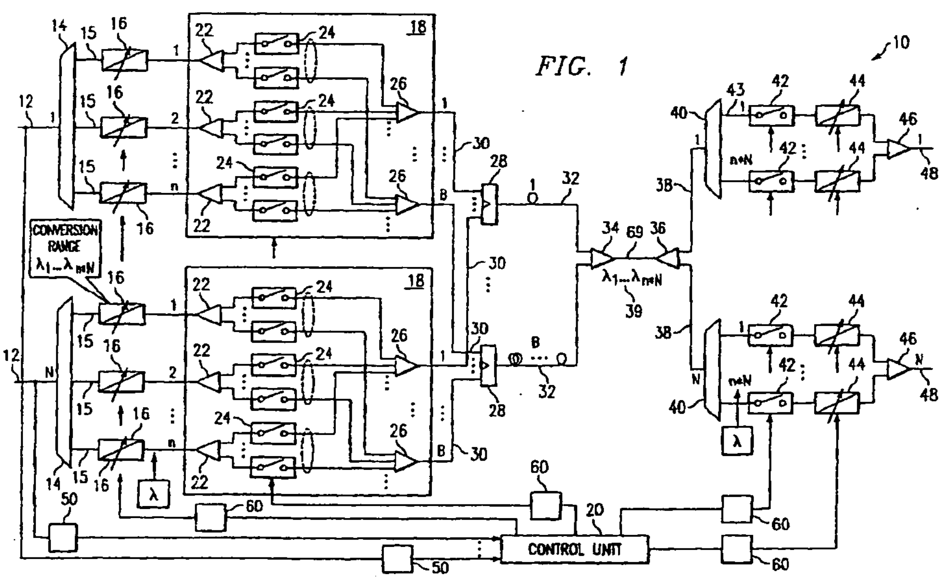
(54) Optical IP switching router architecture

(57) An optical Internet Protocol switching method and system are disclosed for switching data packets entirely in the optical domain. The method of the present invention includes the steps of receiving a plurality of data packets at an optical switch and extracting the header information for each data packet for processing at a control unit. The data packets can be demultiplexed at a plurality of demultiplexers and each data packet assigned a different internal wavelength. The method of the present invention can route each data packet to one or more delay buffers based on a current output status. The data packets can be combined into a single output from the delay buffers and broadcast to a plurality of outputs channels. The method of the present invention can select one or more data packets to output through at least one of the output channels and can convert the assigned internal wavelengths of the selected data packets to their original wavelength using a tunable wavelength converter. The selected data packets can be multiplexed together for transmission on an output Wave Division Multiplexing ("WDM")fiber.

FIG. 1



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[0013] A still further need exists for an optical IP switching router architecture that combines optical space switches with optical wavelength converters to improve the flexibility and throughput of optical networks. Such an architecture can provide an optical IP data packet router structure for fast all-optical data packet switching in a WDM system.

[0014] An even further need exists for an optical IP switching router architecture that uses WDM at both the switch input and the switch output, and thus provides full wavelength domain flexibility for data packet switching among nodes of core data networks.

[0015] A still further need exists for an optical IP switching router architecture that can combine fast SOA gates and wavelength converters at the switch input to resolve conflicts in the wavelength domain. Such an architecture can provide for switching IP data packets in a completely optical manner.

[0016] An even further need exists for an optical IP switching router architecture with reduced component requirements and reduced physical size, as compared to previous such architectures.

[0017] The present invention provides an optical IP switching system and method that substantially eliminates or reduces disadvantages and problems associated with previously developed systems and methods for switching optical data packets across a network

[0018] More specifically, the present invention provides an optical IP switching method and system for switching data packets entirely in the optical domain. The method of the present invention includes the steps of receiving a plurality of data packets at an optical switch and extracting the header information for each data packet for processing at a control unit. The data packets can be demultiplexed at a plurality of demultiplexers and each data packet assigned a different internal wavelength. The method of the present invention can route each data packet to one or more delay buffers based on a current output status. The data packets can be combined into a single output from the delay buffers and broadcast to a plurality of outputs channels. The method of the present invention can select one or more data packets to output through at least one of the output channels and can convert the assigned internal wavelengths of the selected data packets to their original wavelength using a tunable wavelength converter. The selected data packets can be multiplexed together for transmission on an output Wave Division Multiplexing ("WDM")fiber.

[0019] The present invention provides an important technical advantage of an optical IP switching router architecture that can switch IP data packet payloads in an all-optical manner.

[0020] The present invention provides another technical advantage of an optical IP switching router architecture with fast data packet switching capability.

[0021] A still further technical advantage of the optical IP switching router architecture of the present invention is that it can be directly migrated to a WDM input/output for each port.

[0022] An even further technical advantage of the optical IP switching router architecture of the present invention is its ability to include broadcast and multicast functions at the switch level.

[0023] Yet another technical advantage of the optical IP switching router architecture of the present invention is that it can combine optical switches with optical wavelength converters to improve the flexibility and throughput of optical networks.

[0024] Still another technical advantage of the optical IP switching router architecture of the present invention is the ability to use WDM at both the switch input and the switch output to provide full wavelength domain flexibility for data packet switching among nodes of core data networks.

[0025] Even further, the optical IP switching router architecture of the present invention provides the technical advantage of combining fast SOA gates and wavelength converters at the switch input to resolve conflicts in the wavelength domain.

[0026] Yet another technical advantage of the optical IP switching router architecture of the present invention is its reduced component requirements, which can reduce the physical size of a switching router as compared to previous such architectures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] For a more complete understanding of the present invention and the advantages thereof, reference is now made to the following description taken in conjunction with the accompanying drawings in which like reference numerals indicate like features and wherein:

FIGURE 1 is a block diagram of an optical IP switching router incorporating an embodiment of the optical IP switching router architecture of the present invention;

FIGURES 2a and 2b are block diagrams of an embodiment of the present invention that segregates broadcast/multicast functions; and

FIGURE 3 is a close-up block diagram of space switch 18 of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0028] Preferred embodiments of the present invention are illustrated in the FIGURES, like numerals being used to refer to like and corresponding parts of the various drawings.

[0029] FIGURE 1 shows one embodiment of the optical IP switching router architecture for IP data packet switching of the present invention. Optical switch 10 can have 1 to N input WDM fibers 12, where N is an arbitrary number whose value is only limited by size and technol-

to avoid the potential conflict. Control unit 20 can track every data packet wavelength so that it does not cause a conversion to occur that avoids one conflict only to cause another. Data packet wavelengths are converted to currently free wavelengths.

[0037] At the output of input wavelength converters 16, each data packet payload can have a different wavelength, even if one or more data packet payloads are going to the same optical switch 10 output. In the event that a large number of incoming data packets have the same wavelength and are going to the same switch output, a simple wavelength conversion may not be enough to avoid conflicts. To avoid a conflict, optical switch 10 can also include delay buffers 32 to insert an appropriate delay between one or more of the data packets intended for the same switch output. Delay buffers 32 can be Fiber Delay Line ("FDL") buffers.

[0038] Unlike prior art electronic switch routers, the present invention can operate without a dedicated delay buffer for every data packet input fiber coming into optical switch 10, and can thus avoid the additional cost and reduced speed of prior art such systems. Prior art electronic switching systems require an optical-to-electric signal conversion for every channel (wavelength) coming into the switching router. Those prior art systems can extract and process header information to route the data packets but to do so they must convert the entire data packet into electric form and temporarily store the data packet payload while processing the header information. This is both costly and slow because it requires a separate memory buffer for every wavelength to store the data packet payload while reading the header information.

[0039] Because the minimum data packet size is typically fixed, as data transmission speed increases - for example, from the most popular speed today (155 megabytes per second) up to the currently possible 2.5 gigabyte or 10 gigabyte per second speeds - the amount of time that a switching router has to process each individual data packet decreases. Prior art methods that perform an optical-to-electric conversion of the entire data packet become overly problematical as transmission speeds increase due to limits in the data processing speed of prior art switches and routers. Additionally, optical-to-electric conversion is limiting in that individual data packets must be synchronized to recreate each data packet at the output to optical switch 10.

[0040] The optical IP switching router architecture of the present invention can avoid these problems by tapping a single channel (wavelength) on each input WDM fiber 12. This channel can contain all of the control information for the input WDM fiber 12. Additionally, the entire process except for the header information extraction (control information extraction), is entirely optical. Furthermore, extraction of the header information requires manipulation of less data when compared to extraction of the entire data packet. The present invention allows multiple data packet payloads to be processed together in an optical format This can provide the capability for much faster speeds than are possible with current switching technology. The present invention, for example, can process data through-puts in excess of 40 gigabits. The optical IP switching router architecture of the present invention is also transparent, meaning that optical switch 10 can operate independently of data transmission speed.

[0041] Extracted header information is reassembled with the its respective data packet payload at the output of optical switch 10. Electric-to-optical converters 60, at the output of control unit 20, can convert the header information back to an optical format to be reassembled with its associated data packet payload. The present invention thus can reduce the number of optical-to-electric conversions (and vice versa) from that of the prior art (one conversion for each wavelength) to just a single conversion for each input WDM fiber 12 to optical switch 10.

[0042] From input wavelength converter 16, data packet payloads (each having a different wavelength) can be forwarded to one of 1 to N optical space switches 18. Optical space switches 18 (one for each input WDM fiber 12) are similar to electronic space switches but operate entirely in the optical domain. Optical space switches 18 are shown in FIGURE 1 as nxn space switches, but they can be scaled to fit any switch architecture. A nxn space switch, as shown in FIGURE 1, splits each incoming signal into n signals identical to the incoming signal. As examples, three-by-three, four-by-four, five-by-five (and so on) space switches can split each incoming data packet signal into three, four and five individual signals (and so on), as the case may be.

[0043] Input splitters 22 split the incoming signals within optical space switches 18. Optical space switches 18 can have up to n input splitters each, corresponding to the n wavelengths carried on each input WDM fiber 12. Input splitters 22 can split an incoming signal into as many component signals as required by optical space switch 18 (e.g., split into two signals for a nxn optical space switch 18). Once split, each signal can be forwarded to an input Semiconductor Optical Amplifier gate (SOA) 24.

[0044] Each input SOA 24 is like an on/off switch that can either pass a signal when "on," or can block a signal from passing when "off." Input SOAs 24 can be controlled by an input signal from control unit 20. Each input SOA 24 can have a driver to control its operation. For example, if the current through an input SOA 24 is one value (e.g., 200 milliamps), then input SOA 24 can become transparent and pass an incoming signal through it. Alternatively, if the current through an input SOA 24 is a lesser value (e.g., 50 milliamps), the input SOA 24 can become obscure and absorb the optical signal, preventing transmission. Input SOAs 24 can provide the capability for fast data packet switching.

[0045] Based on a 40-byte data packet (the smallest data packet in the IP format) and a transmission speed

[0054] One reason for combining all of the data packets into a single combined signal 39 along a combined fiber 69 is that information arriving on distinct input WDM fibers 12 may be needed in a combined form at the output of optical switch 10, along one or more different output WDM fibers 48. Buffer output coupler 34 can provide this function by coupling all of the data packet outputs into combined signal 39. Combined signal 39 can be split along perhaps different parameters and along different output WDM fibers 48 than that on which the data packets originally entered optical switch 10. Information (data packets) that may have arrived at optical switch 10 along distinct input WDM fibers 12 can thus be appropriately delayed and recombined such that information from two or more input WDM fibers 12 can be combined into a single output WDM fiber 48.

[0055] Another advantage of combining all of the input data packets, regardless of their wavelength, into a single combined fiber 69 is that it can provide for a multicast/broadcast function, voice over IP, and video on demand. The optical IP switching router architecture of the present invention can provide these functions because coupling together the information coming into optical switch 10 into a combined fiber 69 allows every output from optical switch 10 to selectively receive all or part of the information carried on combined fiber 69. Combined signal 39 need not be separately assigned to each switch output, but instead can serve as a source feed that every switch output can tap into. All or part of combined signal 39 can thus be routed to any or all switch outputs.

[0056] Combined signal 39 can be forwarded by buffer output coupler 34 to output splitter 36, which can split combined signal 39 into N individual signals having the same information as combined signal 39 and each carried on N output channels 38. Output channels 38 can feed into N output demultiplexers 40. Each output demultiplexer 40 can thus receive all the data coming into optical switch 10.

[0057] Output demultiplexers 40, one for each of the N output WDM fibers 48, can separate out the different wavelengths carried within combined signal 39. On the downstream side of output demultiplexer 40s there can be up to (n x N) individual fibers 43, one for each of the possible (n x N) different data packet wavelengths. On each individual fiber 43 there can be an output SOA 42 followed by an output wavelength converter 44. Control unit 20 can provide a control signal to output SOAs 42 such that, in the same manner discussed for input SOAs 24, a particular wavelength can either be allowed to pass through or can be absorbed.

[0058] Each signal allowed to pass through an output SOA 42 can be forwarded to an output wavelength converter 44. Output wavelength converters 44 are tunable wavelength converters. Output wavelength converters 44 perform the same function as input wavelength converters 16 and can convert the wavelength of a particular data packet. In particular, output wavelength converters 44 can convert the wavelength of a data packet at the output of optical switch 10 back to the original wavelength that data packet had at the input to optical switch 10. At output couplers 46, all of the wavelengths selected by control unit 20 through output SOAs 42 to comprise the signal for a particular output WDM fiber 48 are combined and forwarded from optical switch 10 along output WDM fibers 48.

[0059] On average, the number of inputs into output demultiplexers 40 equals the number of outputs from output coupler 46. However, the number can differ at a particular point in time, depending on which wavelengths are allowed to go through, and which wavelengths are blocked by, output SOAs 42. As previously discussed, data packets arriving at optical switch 10 along different input WDM fibers 12 can be combined at the output of optical switch 10 onto one or more output WDM fibers 48. For example, a data packet could arrive at optical switch 10 along a single fiber (e.g., fiber 1) and be split and selected for output along every output WDM fiber 48. This is one example of a multicast function data packet.

[0060] In prior art switching architectures, bottlenecks can occur at the output of a coupler, such as buffer output coupler 34, because the output from the combined delay buffers 32 can have up to (n x N) wavelengths. Current switching technology is only capable of a total of 32 wavelengths on a single fiber, which limits the number of input WDM fibers 12 that can be used depending on the number of wavelengths per fiber. In the embodiment of this invention shown in FIGURE 1, however, optical switch 10 can potentially process 256 different wavelengths per internal fiber. Therefore, if each input WDM fiber 12 can hold 32 wavelengths (n), then N can be equal to eight (i.e., there can be eight input WDM fibers 12). Furthermore, the optical IP switching router architecture of the present invention, because of its transparency to transmission speed, can be scaled up to some five to six terrabits per second. The capacity of the present invention is thus dependent upon, and limited by, the capacity of input WDM fibers 12 and output WDM fibers 48. However, even with the current limitation of 32 wavelengths per fiber, the number of input WDM fibers 12 can be increased using the present invention.

[0061] FIGURES 2a and 2b show another embodiment of the optical IP switching router architecture of the present invention. The embodiment of FIGURES 2a and 2b performs the same function as the embodiment of this invention shown in FIGURE 1. However, the embodiment of FIGURES 2a and 2b has reduced component requirements. The embodiment of the present invention shown in FIGURES 2a and 2b can assign separate wavelengths to the multicast and broadcast functions at the input to optical switch 10. A smaller number of output SOAs 42 can then be used as compared to the embodiment of FIGURE 1. Further, the number of tunable output wavelength converters 44 can likewise be

portion of optical switch 10 to control the routing of the unicast data packets because they have been pre-selected at the input to optical switch 10 to go to a particular output WDM fiber 48. The unicast data packets can be routed automatically through the operation of unicast demultiplexers 70. Unicast demultiplexers 70 and broadcast demultiplexers 72 can be broadband filters that allow through only certain wavelengths.

[0070] Output SOAs 42 and output tunable wavelength converters 44 of FIGURES 2a and 2b perform the same function as in the embodiment of the present invention shown in FIGURE 1. Control unit 20 can likewise provide a control signal input to output SOAs 42 and output wavelength converters 44 to control which broadcast/multicast data packets are allowed through output SOAs 42. Broadcast/multicast data packets allowed through output SOAs 42 can have their wavelengths converted by output tunable wavelength converters 44 to avoid conflicts in the same manner as discussed above with regards to FIGURE 1. Data packets allowed through output SOAs 42 can be broadcast to every output WDM fiber 48.

[0071] The embodiments of the present invention shown in FIGURE 1 and FIGURES 2a and 2b can both provide transparent optical data packet switching for internet traffic. They also can both provide multicast and broadcast functionality at the switch level. The active components in optical switch 10 of either embodiment can handle one wavelength at a time to reduce the cross-talk among channels.

[0072] FIGURE 3 is a close-up block diagram of an optical space switch 18 of the present invention as shown in FIGURE 1 and FIGURES 2a and 2b. Wavelength fibers 15 enter optical space switch 18 and progress through input splitter 22, input SOAs 24, and input couplers 26, as described above as part of FIGURE 1. The operation of optical space switch 18 can be controlled by control unit 20 as previously described.

[0073] Although the present invention has been described in detail herein with reference to the illustrative embodiments, it should be understood that the description is by way of example only and is not to be construed in a limiting sense. It is to be further understood, therefore, that numerous changes in the details of the embodiments of this invention and additional embodiments of this invention will be apparent to, and may be made by, persons of ordinary skill in the art having reference to this description. It is contemplated that all such changes and additional embodiments are within the spirit and true scope of this invention as claimed below.

Claims

1. An optical IP switching method, comprising the steps of:

   receiving a plurality of optical data packets at an optical switch, wherein each data packet has a payload and header information;
   extracting the header information from each of said plurality of data packets;
   converting the header information for each of said plurality of data packets from an optical format to an electric format;
   processing the header information for each of said plurality of data packets at a control unit to generate control signals to control data packet payload routing through the optical switch;
   routing the payload from each of said plurality of data packets through the optical switch in an all-optical manner to at least one desired switch output;
   converting the header information for each of said plurality of data packets back to an optical format; and
   recombining the payload and header information for each of said plurality of data packets for transmission on at least one output fiber from said at least one desired switch output.

2. The method of Claim 1, wherein said routing step further comprises:

   demultiplexing said plurality of data packet payloads at a plurality of demultiplexers;
   assigning each of said plurality of data packet payloads an internal wavelength;
   forwarding each of said plurality of data packet payloads to one or more delay buffers based on a current output status;
   combining said plurality of data packet payloads at the output of said one or more delay buffers and broadcasting said combined plurality of data packet payloads to a plurality of outputs;
   selecting one or more data packet payloads from said combined plurality of data packet payloads to output through at least one of said plurality of outputs;
   converting said internal wavelength of said selected one or more data packet payloads using a tunable wavelength converter; and
   multiplexing said selected one or more data packet payloads together for transmission on an output fiber from said at least one of said plurality of outputs.

3. The method of Claim 2, wherein said demultiplexing step further comprises demultiplexing said plurality of data packet payloads based on wavelength.

4. The method of Claim 2, wherein said assigning step comprises converting an original wavelength of each of said plurality of data packet payloads to said internal wavelength using a wavelength converter.

a control unit for processing said converted header information and generating control signals to control data packet payload routing through said optical IP switching router;
a plurality of input wavelength converters for assigning each of said plurality of data packet payloads an internal wavelength;
a plurality of optical space switches for routing each of said plurality of data packet payloads to one of one or more couplers based on a current output status, said one or more couplers for coupling and routing at least one of said each of said plurality of data packet payloads to one of one or more delay buffers;
a buffer coupler for combining said plurality of data packet payloads into a combined output from said one or more delay buffers;
an output splitter for broadcasting said combined output to a plurality of output channels;
an output demultiplexer for each of said plurality of output channels for demultiplexing each of said broadcast combined outputs;
a plurality of output SOA's for selecting one or more data packet payloads from said plurality of data packet payloads for transmission through at least one of said plurality of output channels;
a plurality of tunable wavelength converters for converting said internal wavelength of said selected one or more data packets;
a plurality of electric-to-optical converters for converting said electric form header information back to optical form for recombining said header information with its respective data packet payload; and
a plurality of multiplexers for multiplexing said selected one or more data packets together for transmission out of said at least one of said plurality of output channels on an output fiber.

29. The router of Claim 28, wherein said demultiplexers demultiplex said plurality of data packet payloads based on wavelength.

30. The router of Claim 28, wherein said input wavelength converters assign a different internal wavelength to each of said plurality of data packet payloads.

31. The router of Claim 28, wherein said plurality of input wavelength converters are tunable wavelength converters.

32. The router of Claim 28, wherein said plurality of input wavelength converters are fixed wavelength converters.

33. The router of Claim 28, wherein said plurality of optical space switches each comprise;

a plurality of input splitters for splitting each of said plurality of data packet payloads into a second plurality of data packet payloads, wherein each of said second plurality of data packet payloads is identical to the split data packet payload; and
a plurality of input SOA's for selecting and forwarding to one of said one or more couplers one of said second plurality of data packet payloads for said each of said plurality of data packet payloads that is split.

34. The router of Claim 28, wherein said current output status is an intended output port for said each of said plurality of data packets.

35. The router of Claim 28, wherein said control unit further comprises software instructions to control functionality of said control unit.

36. The router of Claim 28, wherein said one or more delay buffers are optical fiber delay line buffers.

37. The router of Claim 28, wherein one of said one or more delay buffers provides zero delay.

38. The router of Claim 28, wherein each of said one or more delay buffers provide a delay of one or more unit increments.

39. The router of Claim 38, wherein said one or more unit increments are equal to the average size of said plurality of data packets.

40. The router of Claim 28, wherein said optical IP switching router is independent of the rate of transmission of said plurality of data packets.

41. The router of Claim 28, wherein said optical IP switching router provides broadcast and multicast capability, voiceover IP and video-on-demand.

42. An optical IP router switching method using wavelength domain multiplexing to provide multicast and broadcast functions, comprising the steps of:

receiving a plurality of optical data packets at an optical switch, wherein each data packet has a payload and header information;
extracting the header information from each of said plurality of data packets;
converting the header information for each of said plurality of data packets from an optical format to an electric format;
processing the header information for each of said plurality of data packets at a control unit to

fibers.

55. The method of Claim 54, wherein said optical switch is a wave division multiplexing ("WDM") switching router and wherein said one or more input fibers and said at least one output fiber are WDM fibers.

56. The method of Claim 55, wherein one or more of said plurality of data packets are received at said optical switch along a common one of said on or more input fibers and transmitted from said optical switch along a plurality of different output fibers.

57. An optical IP switching router using wavelength domain multiplexing to provide multicast and broadcast functions, comprising:

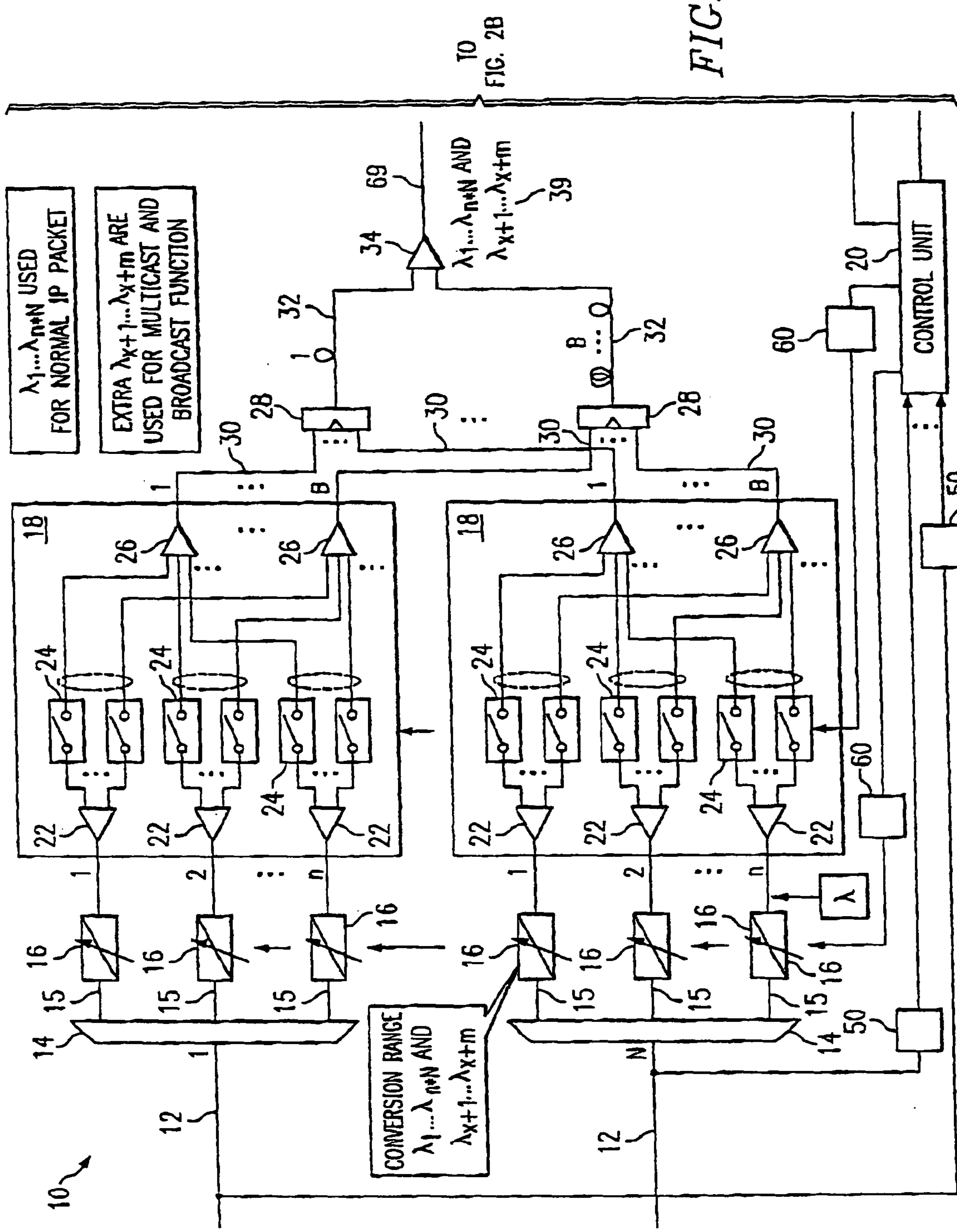
a plurality of input demulfiplexers for receiving a plurality of optical data packets and demultiplexing the payloads of said plurality of data packets;
a plurality of optical-to-electric converters for converting header information from each of said plurality of data packets into electric form;
a control unit for processing said converted header information and generating control signals to control data packet payload routing through said optical IP switching router,
a plurality of input tunable wavelength converters for assigning each of said plurality of data packet payloads an internal wavelength based on whether said each of said plurality of data packets is a unicast data packet or a broadcast/multicast data packet;
a plurality of optical space switches for routing each of said plurality of data packet payloads to one of one or more couplers based on a current output status, said one or more couplers for coupling and routing at least one of said each of said plurality of data packet payloads to one of one or more delay buffers;
a buffer coupler for combining said plurality of data packets into a combined output from said one or more delay buffers;
an output splitter for broadcasting said combined output to a plurality of output channels;
a unicast demultiplexer for each of said plurality of output channels for demultiplexing out of said broadcast combined output one or more unicast data packet payloads;
a plurality of fixed wavelength converters for converting the wavelength of each of said one or more unicast data packet payloads;
a broadcast demultiplexer for each of said plurality of output channels for demultiplexing out of said broadcast combined output one or more broadcast/multicast data packet payloads;
a plurality of output SOA's for selecting one or more broadcast/multicast data packet payloads from said one or more broadcast/maltiicast data packet payloads for transmission through at least one of said plurality of output channels;
a plurality of tunable wavelength converters for converting said internal wavelength of said selected one or more broadcast/multicast data packet payloads;
a plurality of electric-to-optical converters for converting said electric form header information back to optical form for recombining said header information with its respective data packet payload; and
a multiplexer for each of said plurality of output channels for multiplexing said selected one or more broadcast/multicast data packets together with said one or more unicast data packets for transmission out of said at least one of said plurality of output channels on an output WDM fiber.

58. The router of Claim 57, wherein said demultiplexers demultiplex said plurality of data packet payloads based on wavelength.

59. The router of Claim 57, wherein said control unit further comprises software instructions to control functionality of said control unit.

60. The router of Claim 57, wherein said control unit provides a control signal based on the header information to control the routing of said plurality of data packet payloads through said optical IP switching router.

61. The router of Claim 57, wherein said one or more delay buffers are fiber delay line buffers.


$\lambda_1 \ldots \lambda_{n*N}$ USED FOR NORMAL IP PACKET
EXTRA $\lambda_{x+1} \ldots \lambda_{x+m}$ ARE USED FOR MULTICAST AND BROADCAST FUNCTION
TO FIG. 2B
$\lambda_1 \ldots \lambda_{n*N}$ AND $\lambda_{x+1} \ldots \lambda_{x+m}$
CONVERSION RANGE $\lambda_1 \ldots \lambda_{n*N}$ AND $\lambda_{x+1} \ldots \lambda_{x+m}$
CONTROL UNIT
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69

FIG. 2A

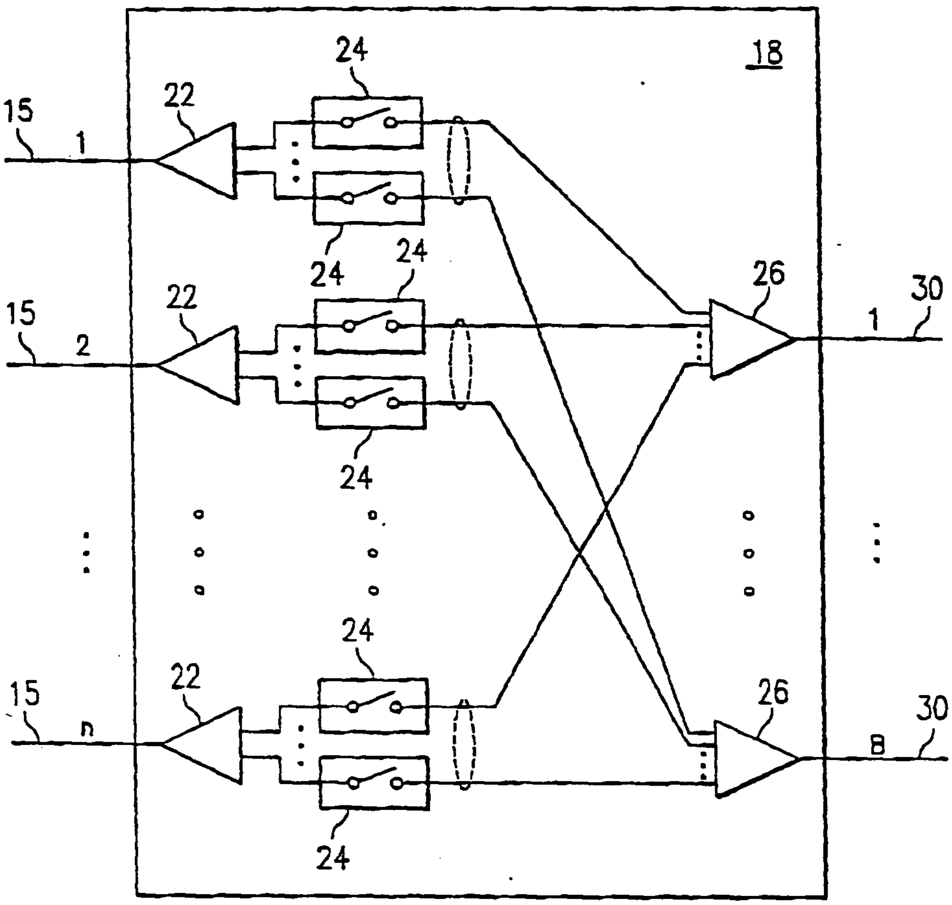

FIG. 3